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Battelle Technical Review

IN THIS ISSUE

Statistics In Research

AERONAUTICAL SCIENTIST

FRED BAGBY

AS EVERY SCIENTIST AND engineer knows, fundamentals are the same in many apparently unrelated fields. For this and other reasons, technologists can and do work successfully in several areas of technology. Fred Bagby has found that such varied experience is of greater value than intense specialization. He points out that though we live in an age of specialization, the overlapping of specialties is also a hard technical fact. Problems drawing upon small areas for their solutions can be handled best by those with the wide experience that comes from working in a variety of technical fields and who may apply unorthodox approaches and ideas to the solution of such problems.

Fred speaks from experience. Like other technologists at Battelle, he has worked successfully in several fields since joining the Institute in 1946. In his first investigations at Battelle, he applied principles of smokeless combustion to the development of improved stoves, furnaces, boilers, and water heaters. Later, he studied the application of low-frequency vibrations to rock drilling. More recently he has participated in numerous classified aircraft and guided-missile engineering investigations. Emphasis in these investigations has been in aerodynamics and flight propulsion, and the relation of these fields to air weapon systems development. He found certain basics common to all three fields, and his earlier experience has been helpful in the more recent investigations.

Before his association with Battelle, Fred served as a production design engineer in the Columbus plant of Curtiss-Wright Corporation's Airplane Division. His professional training was gained at the University of Utah where he received a B.S. in mechanical engineering in the field of aeronautics.

Fred is an active member of the American Society of Mechanical Engineers and of the Institute of Aeronautical Sciences.

Two daughters, nine and six, have first call on Fred's leisure time. Of his hobbies, he follows spectator sports by choice, but when it comes to "do-it-yourself", it is workshop and gardening.

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BATTELLE TECHNICAL REVIEW

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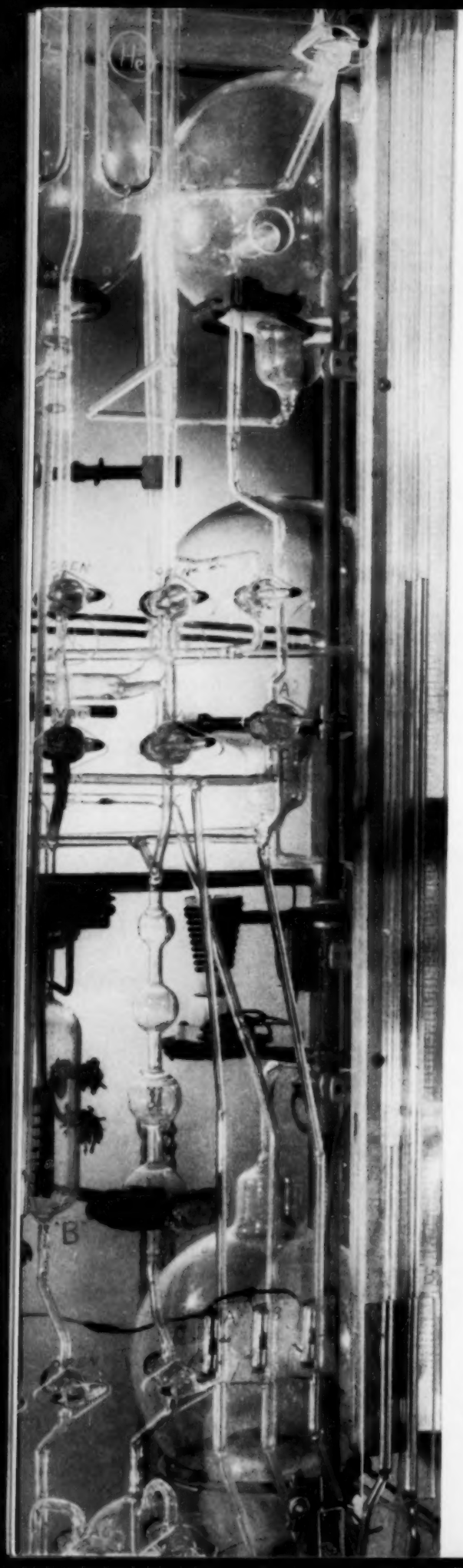

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Adsorption apparatus used to determine surface area, porosity, and adsorption characteristics of solids.

COMMENT

Advertising and Technological Progress

ADVERTISING IS AN ACTIVITY now accounting for the expenditure of $8.5 billion per year in the United States—over twice the amount spent on technical research. Like research, advertising is extremely important to our economy. Without it, mass employment at good wages, high standards of living, and constant growth in the production of goods and services would be impossible. Advertising, although by its nature much different from technology, is actually one of the most important corollaries to research effort. It is the economic function, which by its development of mass markets, makes industrial research needed and financially profitable.

Advertising plays other roles in technological progress. One of these is its dramatization of science and technology, and its interpretation of research to the public. It has played a major part in the development of public attitudes that favor both industrial and governmental expenditures for scientific investigation. Advertising also exercises an important influence on the execution of research through its support of technical, trade, and business publications, whose editorial columns are important means of communication among technologists and between technical people and management.

Advertising helps research in still other ways. Advertising directors and executives of advertising agencies come in contact with the people who distribute merchandise and with the consuming public. They, in addition, have well-developed techniques for measuring public psychology and are able to gage what customers want in products and in production innovation. Thus, the opinions of advertising people are valuable to management in research planning and in product development. Not infrequently when a major research program is being considered, advertising representatives sit in on planning conferences, guiding technical personnel and management on the preferences of customers.

Being close to the public, advertising representatives often recognize consumer wants and needs before they are visible to technologists or to industrial management. It is not uncommon for advertising directors or agency account executives to suggest ideas for new products. Tips as to unfulfilled consumer needs have led to many notable research accomplishments.

The closeness of advertising people to research is emphasized by many instances when advertising agencies have resolved difficult problems of their clients by pointing out the need for research and even directing them into fruitful areas of technical endeavor. When one considers that the underlying function of an advertising firm is to help its clients increase sales and profits, such advisory aid is decidely in order.

No doubt the future will bring even closer liasion between research and advertising. The joining of hands of these two functions will further accelerate technological and economic progress.

Clyde Williams

President and Director,
Battelle Memorial Institute

ELECTRONIC PURSUIT APPARATUS

The "electronic pursuit apparatus" was designed and developed at Battelle to aid Army psychologists in conducting basic research. Its purpose is the evaluation of human factors involved in such military tasks as aiming weapons and guiding vehicles. In tests, subjects are required to track, on a large oscilloscope, a bright dot whose movements can be varied considerably by an elaborate control system. The new device, actually a special-purpose computer, includes timing and counting devices. A paper-tape recording device records each subject's performance for later analysis. The apparatus was built for the Army Medical Research Laboratory.

Statistics in Research

by GLENN H. BEATTY

Use of statistics in the design of research is expanding rapidly. It can increase the possibilities of success and reduce research costs.

"The characteristics which distinguish the present-day statistician are his interest and skill in the measurement of the uncertainty of conclusions."—*G. W. Snedecor*

AN EXHIBITION OF CHECKERS is an impressive experience. One man plays 20 or 30 challengers at the same time. As he pauses before each board, he sizes up the situation briefly, makes his move, and goes on. Each challenger may study the situation until the master has made the rounds and is back again. Yet before long, all have succumbed to the unerring play of the man across the table. One by one, they drop out.

Here is a seemingly simple game, yet one filled with tricks; many have spent years of study at it. The history of the game has provided classic matches which have descended with names familiar to all tournament players. Black Doctor, Double Corner, Edinburgh, Maid of the Mill, Old Fourteenth, Tillicoultry, Waterloo—these and many more are known to the champions play by play. A photographic mind is a common trait of the experts; they store hundreds of games in their memories and when a familiar situation develops in a match, they know all the winning moves.

In research, too, it is important to know the winning moves. This is especially true for the accumulation and interpretation of quantitative data. Here is the statistician's realm. The field of application is immaterial; his business is making sense out of numbers. He goes about his job in an objective way, not trusting his senses, but guided by logic. He ferrets out obscure results and measures their reliability with care. And he uses methods that do this efficiently and economically, extracting all the information worth having without wasting motions.

The science of statistics is like the game of checkers in two important respects. In the first place, skill in the use of modern statistical theory enables one to cope with a wide variety of problems. In the second place, statistical methods include many established procedures by means of which statisticians are able to recognize and pursue problems with adroitness.

SCOPE OF APPLICATION

In 1948 and 1949, studies were made in New Mexico of the intensity and distribution of rainfall produced by introducing sublimation nuclei into the atmosphere. Careful planning made possible a separation of the effects of naturally occurring nuclei from those introduced artificially. Thus, on at least two days, which involved the greatest amounts of seeding, it was found with a probability factor greater than 10^{20} to 1 that practically all the 10^9 (1,000,000,000) tons of rain that occurred on each of these days were the result of seeding.

Quite a different kind of research to which statistics was applied was the work of Kinsey and his associates on sexual behavior. Little needs to be added to the publicity already accorded his two publications on this subject. The point is that the importance of statistics to the enterprise was demonstrated by the fact that a special committee of the American Statistical Association was appointed in 1950 to review the methods used in the study.

Many applications of statistics can be found in medical research. The case for association between smoking and lung cancer furnishes a good example. The controversy which this question has raised recently is rooted in the familiar adage, "You can prove anything by statistics." There is disagreement whether the evidence at hand warrants a conclusion that smoking and lung cancer are related. More data, properly analyzed and interpreted, could probably provide a conclusion acceptable to most parties.

The above examples should suffice to show the flexibility of statistics. If it has been helpful in such diverse fields as physics, sociology, and medicine, what limits are there to its use? The possibilities are everywhere. But because the development of statistics has been rapid and its methods not always understood, there have been instances of improper application, interpretation, and transmittal of the statisticians' analyses of data. This has often led to criticism and adverse publicity and tended to prevent the fullest possible use of the technique. Yet statistics has continued to gain increased acceptance because of its real value in many fields. In technology, its use has grown steadily, and it is achieving recognition as one of the most valuable of research tools.

Design of Experiments

Like the checker champion with his standard games, the practicing statistician has at his disposal many proven experimental plans. The champ exploits his advantage by trying to lead every game into a situation he has encountered before. Similarly, the statistician examines each new problem with the purpose of taking an approach which is most likely to yield the answers. Getting off to a good start is the important thing. The statistician has the best chance of success when consulted at the beginning of a research program.

Since joining Battelle in 1948, Glenn Beatty has conducted operations research studies and has served as a consultant in statistics. He has carried on statistical studies in many fields, but particularly in metallurgy, biology, agriculture, and chemistry. He received a U.N. service medal for military operations research in Korea. Earlier, he served as an instructor in mathematics at Iowa State College where he received his M.S. in statistics. Still earlier, he received his B.A. in mathematics from The Ohio State University.

Typical Uses of Statistics in Research

Determination of:

- Characteristics of particle size distribution.
- Insect killing effects of chemical compounds.
- Effects of fertilizers on crops and flowers.
- Properties of paper products.
- Strength of adhesives.
- Effects of chemical treatments on wear properties of wool.
- Durability of plastic pipe.
- Designs of better ball bearings.
- Electrical conductivity of wires in various applications.
- Better ways of electroplating metal.
- Compositions of desirable new alloys.
- Compositions for improved ceramics.
- Designs for automatic check-weighing machines.
- Format and treatment of data for market and opinion surveys.

The science of experimental design, as it is known today, grew out of the pioneering work of R. A. Fisher, who is still contributing to the advancement of statistics. The purpose of experimental design is to get the maximum amount of information per unit of cost. This requires careful advance planning with particular regard to the possible outcomes of an experiment and the interpretation of each. Some designs that have proved their utility have acquired well-known names. Any statistician needs no introduction to randomized block designs, latin squares, incomplete blocks, split-plot designs, and other standard ones. The field is fertile and growing fast; new designs are being developed and tested, such as factorial experiments using fractional replication, chain-block designs, and variations on older designs.

Although the list of statistical designs is long and outwardly disconnected, certain features are common

to all. They all provide for arranging a number of "levels" of a number of "factors" together in various combinations. The factors may be either measurable variables, such as time, length, temperature, etc., or classes of objects, such as metal, crop, chemical, etc. The first type of factor has quantitative levels, such as one hour, two hours, four hours, whereas the second type of factor has qualitative levels, such as iron, lead, copper. Except for this difference in interpretation, the terms factor and level are applicable to anything.

Another feature common to all experimental designs is that provision is made for estimating "experimental error". This term does not imply a mistake; it implies the inability of research workers to reproduce results exactly, which is partly attributable to natural causes (that is, it is the degree of irreproducibility, or accidental variation which cannot be controlled). The isolation and measurement of experimental error is the key feature of all experimental designs and their analysis. Fisher took great care to make this clear. Another important feature common to all varieties of design is randomization. Their analysis depends on having the tests run in random order.

To illustrate the use of statistical designs in research, suppose a general-purpose protective coating is being developed. One of its properties under test is drying time. We call this the dependent variable. Consider as independent variables (factors) the type of material and temperature of application. Material is a *qualitative* factor; its levels might be paper, wood, metal, and plaster. Temperature is a *quantitative* factor; its levels could be 20, 40, 60, etc. degrees Fahrenheit.

To test the drying time for all combinations of materials and temperatures would require 24 specimens. This is called a complete factorial arrangement and it has several advantages. The measurement of interaction is an important one. Suppose the following drying times are observed:

	Wood	Metal
40 F	6 hrs.	10 hrs.
100 F	4 hrs.	4 hrs.

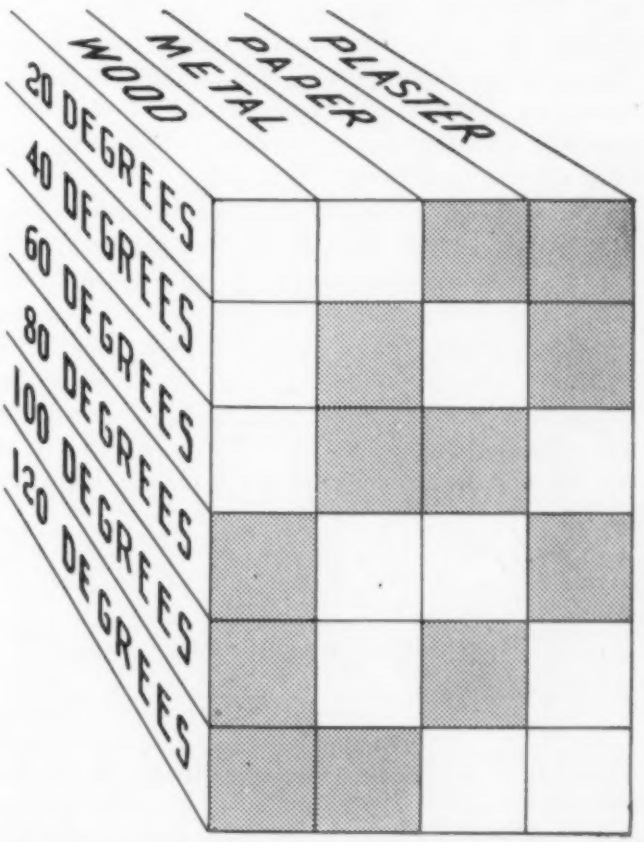
At 40 F, the coating dries faster on wood than on metal, whereas at 100 F, the drying times are the same. This is called an "interaction" effect. The following situation would indicate the absence of interaction:

	Wood	Metal
40 F	6 hrs.	10 hrs.
100 F	4 hrs.	8 hrs.

If the problem warranted 48 specimens, each combination could be tested twice and the reliability of the results would be increased. Usually, though, cost considerations require getting along with the minimum number of tests. This need is met by various types of incomplete factorial designs. The number of specimens in the experiment described above could be reduced to 12 by use of the design shown below. However, this would be done at the expense of losing the interaction measurements, as well as reducing the precision of the results in general. If the experimenter expected no interactions, this would be a good way to cut costs. This is not the end of the possibilities, of course. There are usually many alternative designs for each experiment. The practicing statistician is in the best position to know the various possibilities and to select the right one. His advice can mean the difference between success and failure in getting the right answers, as well as savings in time and money.

Statistical Inference

Setting up an experiment according to a well-chosen plan is the beginning, but not the end, of a good statistical program. Little is gained unless the resulting



In this incomplete factorial design, each blank square represents one test condition. Note that two materials are compared at each temperature and each material is tested at three temperatures. Furthermore, each pair of materials is compared once in the experiment.

data are analyzed correctly. Both parts are essential to a well-conducted experiment, but as separate operations they furnish a convenient division of the field of statistics. The analysis and interpretation of data is spoken of in a broad way as "statistical inference". Its nature must be understood in order to appreciate the function of statistics in research.

Experimental data are nothing more than sample facts. To be useful, they must be generalized to times and places other than the time and place of the experiment. The only worth of research tests is to indicate what to expect *in the future* by people doing similar things *somewhere else*. It is wrong to regard test results as the final objective of research. Statements of research should be qualified by estimates of their uncertainty in predicting future events. This is where the biggest difference exists between statistics and other branches of mathematics. Most mathematical subjects are characterized by exactness; statistics is characterized by inexactness. To be exact, the statistician strives for exact measures of inexactness!

Statistical inference is the statistical mechanism for interpreting experimental results. From the analysis of sample data, the statistician infers the behavior of similar systems in other circumstances. The basis for these inferences is mathematical probability, which is concealed in statistical techniques that are similar in principle but different in detail. The following examples serve to show how this works.

A special type of aircraft rivet was being tested to find within specified limits the percentage defective in each batch of many thousands. The main problem was how many rivets to test. In order to find out, a theoretical analysis was employed. By means of a suitable mathematical formula, the variation to be expected in samples of different sizes was computed and presented in the form of a three-way table. With this as a guide, the question of sample size was answered.

Much correlation analysis (curve-fitting, computation of least-square equations, and so on) is done in the course of research. This technique is used often in metallurgical problems; the following illustration is typical. The strength and hardness of steel is known to depend on the amount of its constituents. Some of the most important of these are carbon, manganese, silicon, and sulfur. Steel companies want to know rather accurately how various combinations of these ingredients affect the properties of their final product. However, to try very many combinations is prohibitive in cost. The same result has been achieved far more simply by testing sample combinations of carbon, manganese, etc., in various proportions and deriving an equation which best fits the data obtained. If the correlation between properties and constituents is strong, such equations can be used to predict properties of steels that have never been poured. In addition, confidence limits on these predictions can be computed from the sample data.

Statistics is characterized by lengthy numerical calculations. This is usually the main consideration in deciding whether to subject the results of experimentation to statistical analysis. Consequently, the development of automatic computing machines was of great significance to this field. The study of steel properties described above, for example, would have been much costlier, would have taken many times longer to accomplish, and would have yielded less information without the use of an electronic computer.

In the eternal quest for truth, the science of statistics plays a vital role. It is a form of insurance against false conclusions and as such is gaining increased acceptance among research workers. Advertising styles tell us that the buying public also is recognizing the importance of statistics in research. The statistician's fee is but a small fraction of the cost of research and is generally repaid in savings of time and tests. It is wise to consider allotting a portion of every research dollar to this use.

UNBELIEVABLE BUMBLE BEE

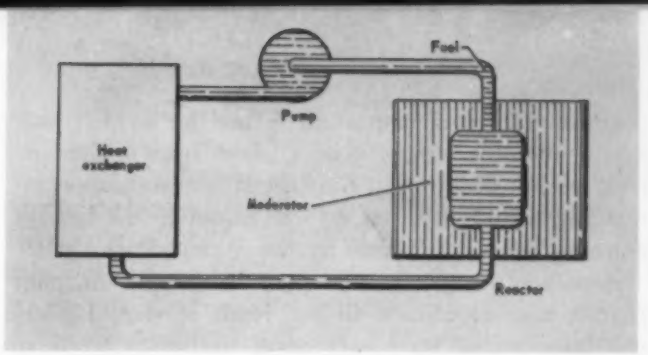
"A designer of aeroplanes calculated recently that the shape of a bumble bee precluded the possibility that it could fly. While he was making his calculations, so he humbly confessed, a bumble bee sped past him like a bullet out of a gun. The truth seems to have been not that the designer knew less, but that the bumble bee could do more."

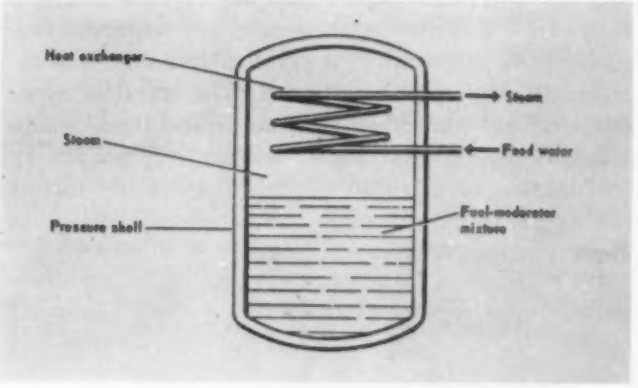
The (London) Times, Review of Industry

Nuclear Power Reactor Controls

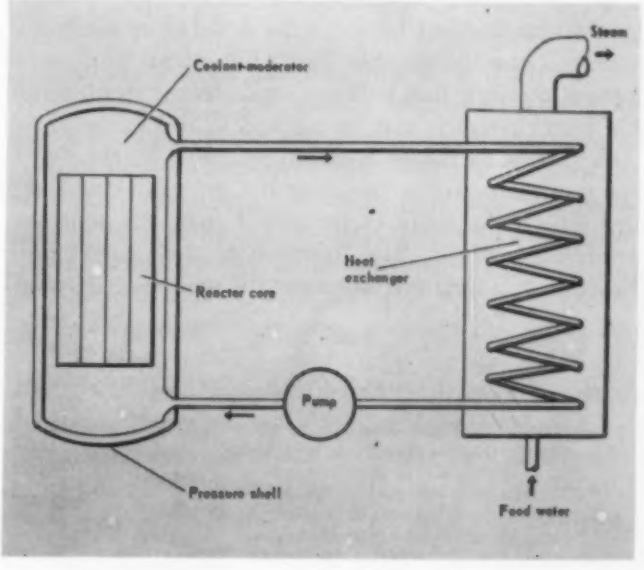
by J. James Stone, Jr.

Exploitation of natural factors for the control of commercial reactors may lead to simpler, almost foolproof, operation.





Most nuclear reactors designed for producing heat power have self-regulating properties that result from physical or geometrical changes in the reactor region. Three typical methods of self regulation are by; thermal expansion of fuel and its explusion from the reactor in the circulating fuel reactor (top); a drop in density of the fuel-moderator mixture due to boiling in the boiling reactor (above); and a decrease in moderator density due to thermal expansion in the pressurized-water reactor (below).



The production of power with nuclear reactors has received, and will continue to receive attention. Within the past year a submarine has put to sea powered by a nuclear reactor. Announcements by the Navy and by the Air Force make it appear likely that surface ships and airplanes will soon follow the lead of the submarine. The development most important to the majority of people, however, is the development of atomic power for the commercial production of electricity. Construction has been started during the past year on the first of such power-source reactors of commercial size and others are expected to follow.

Many nuclear reactors were built and operated prior to the power-source reactors. The knowledge gained through their operation has been invaluable in the present development program. There is, however, a basic difference between the new power reactors and those that preceded them. The earlier reactors were designed expressly to produce neutrons for experimental purposes and for the production of radioactive materials. The new power reactors have been developed primarily for the production of heat. The problem was formerly the removal and dissipation of the heat energy as an unwelcome by-product; the problem is now the removal and conversion of this heat to other forms of energy.

Formerly, the power level, or fission rate, of reactors was controlled in such a manner that the desired neutron level was reached. This could easily be accomplished by sensing the neutron level with appropriate ionization chambers or fission counters and controlling this level with control rods which were servodriven. For a power reactor, this neutron level

[*] Presented originally before the Middle Eastern District Meeting of the American Institute of Electrical Engineers, May, 1955.

is considerably less important. True, the level is proportional to the rate of generation of heat in the system, but for economical heat use it is more important that the heat-generation rate be equal to the rate of consumption of this heat by the attached load.

A power reactor should operate in such a manner that it regulates itself to the load. It should automatically adjust its power level to the demand so that the operation is perfectly stable and nonoscillatory. Such a control may or may not require servomechanisms, depending upon the inherent characteristics of the system designed. The trend is away from auxiliary control devices and toward the development of systems that have "self-control" properties. The purpose of this paper is to review those factors that might be employed by the designer to control power reactors.

How Reactors Are Controlled

A self-sustained nuclear reaction occurs when the number of neutrons produced by fissions just equals the number lost from leakage and absorption. When more neutrons are produced than are lost, the neutron level and also the fission rate increase. Conversely, when fewer neutrons are produced than are lost, the neutron level decays and the fission rate decreases. Thus, for a steady operating level, a delicate balance must be maintained between the number of neutrons produced and the number lost. All methods of control operate through this balance, or "effective mutiplication factor", which may be altered in several ways.

As shown in the illustration on page 7, the most common method of controlling the multiplication factor for a reactor involves the use of rods of a neutron-absorbing material. The insertion of such a rod into the core of a reactor increases the neutron loss and tends to reduce the power level. The withdrawal of such a rod reduces the loss and tends to increase the power level. These control rods may be servo driven by appropriate signals to achieve the operation desired. For flux-producing reactors, the signal for the servo system would be derived from an ionization chamber designed to measure the neutron-flux level of the system. The output of the chamber should be compared with a signal representing the desired operating flux level in the control amplifier, and the difference between these two signals would be used to insert or withdraw the rod so as to reduce the difference.

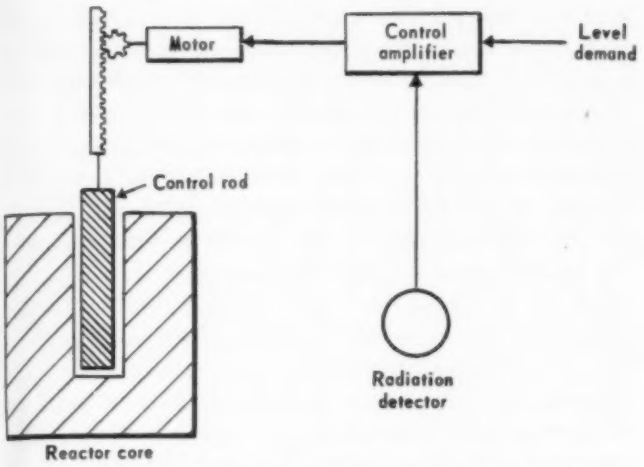
For a power reactor, a control rod would be positioned so as to equalize the rate of heat generation in the reactor and the rate of heat consumption by the load. The use of control rods in this manner normally requires mechanical or hydraulic mechanisms to position them and servo systems to determine their positions.

The temperature of each portion of a reactor may affect the multiplication factor, or "reactivity". If, for an increase in temperature of an element of the system, there is an increase in the multiplication factor, then that element is said to have a positive temperature coefficient of reactivity. Conversely, if a decrease in reactivity accompanies an increase in temperature, then the element is said to have a negative temperature coefficient of reactivity. Of course, a negative temperature coefficient is to be desired while a positive temperature coefficient is to be avoided in a reactor. Both positive and negative coefficients occur in many reactors, as will be shown with the aid of the top sketch, page 7, but the combined effect is usually negative.

Most "temperature effects" are due to expansion of the system or its component parts as the temperature increases. Consider, for example, a reactor, such as that shown in the figure, in which the fuel, or fissionable material, circulates through a loop passing through the core and outside the reactor. An increase in the temperature causes the fuel to expand, and this expansion reduces the number of fissionable nuclei within the core. As a result, the reactivity is decreased; in this case, the reactor has a negative coefficient of reactivity. On the other hand, the tube containing the fuel also expands. This expansion draws more fuel into the reactor and increases the reactivity; thus, the system has a positive coefficient of reactivity. Therefore, the net effect of an increase in fuel temperature may be either positive or negative, depending upon the design of the system.

Thermal expansion or contraction of the moderator also affects the reactivity. The moderator is the ma-

J. J. Stone has been engaged in the development of computing systems and components at Battelle since 1953. He and his colleagues have simultaneously operated Battelle's analog computing facility and participated in educational activities relating to computer technology. Earlier, after serving on the faculty at Virginia Polytechnic Institute, Stone was senior electrical engineer at the Oak Ridge plant of Fairchild Engineering and Airplane Company and then served in the reactor controls department of the National Laboratories at Oak Ridge. Stone received a B.S. in electrical engineering at VPI and an M.S. in communications and electronics at Harvard University.



The earliest form of reactor control utilizes a control rod of neutron-absorbing material. Inserting this rod into the reactor core slows the nuclear reaction while withdrawing it speeds the reaction. A complete control system using this method requires a detector for the level of radiation and means for moving the physical control rod so as to achieve the desired radiation level.

terial used in a reactor to slow down the neutrons. An increase in the temperature of the moderator reduces its density and this may alter its effectiveness. First, the degree of moderation is less, resulting in a higher energy level for the neutrons of the system. Since the nuclear cross sections decrease, in general, with an increase in neutron energy, there is a net decrease in reactivity. Second, there may be a change in the leakage of neutrons through the moderator and shell of the reactor as the density of the moderator decreases. Both of these effects give rise to a negative temperature coefficient. On the other hand, if the kinetic energy of the neutrons lies near a resonance peak in the absorption of one of the neutron absorbers in the system, then an increase in the average energy may cause a decrease in the loss from the system and an increase in reactivity. Here, again, the design of the reactor may determine the size and effect of this factor.

Pressure also affects the reactivity of many reactors. Its effect is similar to that of temperature as just described. If the net fuel content in the reactor increases with pressure, then there is said to be a positive pressure coefficient of reactivity. The same may be said of the effect of the pressure upon the moderator.

For a reactor where the fuel circulates through the core and then through an external loop, the reactivity depends upon the rate of flow of the fuel. When a neutron produces a fission, other neutrons are produced as a result. Approximately 0.75 per cent of the new neutrons produced do not immediately appear in the reactor but appear as the result of a decay of radioactive fission fragments. This decay varies in time among the different products produced by fission and varies from fractions of a second to several minutes. If the fuel circulates, then a portion of the neutrons that normally would appear in the reactor core will be released outside the core and will be lost. Thus, an increase in the flow rate of the fuel causes a decrease in the reactivity of the system. This effect also appears in reverse, for the sudden stoppage of the fuel flow will cause a sudden increase in the multiplication factor of the system. This situation must be guarded against by the safety circuits in the system.

A boiling reactor, shown on page 7, depends upon a given rate of boiling for a unity multiplication factor. A decrease in the rate of boiling results in an increase in the density of the moderator or fuel mixture. This in turn produces an increase in the reactivity, an increase in the boiling rate, and a tendency to regulate the rate of boiling around that level corresponding to a unity multiplication factor.

Thus it becomes evident that many factors influence the kinetic behavior of the nuclear reactor and will alter the means or methods of control. The net effect, or worth, of any of these characteristics depends upon the design of the reactor and the method of coupling the reactor to the rest of the power system.

Methods of Obtaining Control

The majority of nuclear power reactors do not couple directly to the load. A heat reservoir isolates the reactor from the turbines or other machines or devices consuming power. This heat reservoir may be a chest of steam or a volume of fluid used to cool the reactor core and carry the heat energy to the external circuit. Heat energy is removed from this reservoir as required by the load, and the total heat content is maintained approximately constant by the reactor.

The heat power system may be likened to the hydraulic system shown on page 10. A valve at the bottom of a tank of water controls the outflow, which is analogous to the load in the power system. The level of water is analogous to the heat content in the heat reservoir just described. A valve at the top of the tank connected to a source of water controls the inflow of water to the tank; this inflow is equivalent to the heat inflow from the reactor. Two methods may be postulated for the control of the water-inflow valve in this hydraulic model. First, the rate of outflow may be measured and the inflow made to equal this. In theory, the level of water in the tank would remain constant for this method. In practice, slight differences

in the inflow and outflow would exist and the level of water in the tank would gradually increase or decrease, and the water might eventually overflow the vessel.

As a second method of control, the level of water in the tank may be measured and the rate of inflow of water adjusted to maintain the described level. For this method of control no measure of the rate of outflow from the tank is necessary, although the operation of the inlet valve is entirely determined by the outflow.

For the nuclear power system there are also two methods of control. The power output of the reactor may be adjusted to equal the power consumed by the load through measuring directly the power of the load. This corresponds to the first method of control in the hydraulic analogy. Also, some power systems have been designed in such a way that the power output of the reactor is made to equal the power the load should consume. Again, the situation compares with the first method in the hydraulic model. In both of these methods, no direct control exists for the heat content of the system. This heat content determines the temperature and the pressure of the component parts of the system. In order to obtain the most efficient heat-transfer characteristics and the largest amount of power possible with a given amount of material and space, the temperatures and pressures must be near the maximum safe values. A gradual increase in the heat content means a gradual increase in the working temperatures and pressures and could result in materially shortening the life of the system.

As for the hydraulic model, control of the reactor may be based entirely upon a measure of the heat content of the reservoir and, for the reactor, could be derived from the temperature and pressure of this element of the system. Since, for saturated steam, the pressure uniquely determines the temperature, it becomes feasible to regulate, or control, a power reactor entirely by regulating temperatures. It has been shown that the temperature of the fuel and the moderator affect the effective multiplication factor. Consequently, these temperatures may likely be used to control the operating power level. The possibility exists, therefore, that a nuclear power reactor may be designed in such a manner that no control rods are required and the system automatically slaves itself to the load by maintaining the temperatures at the proper levels.

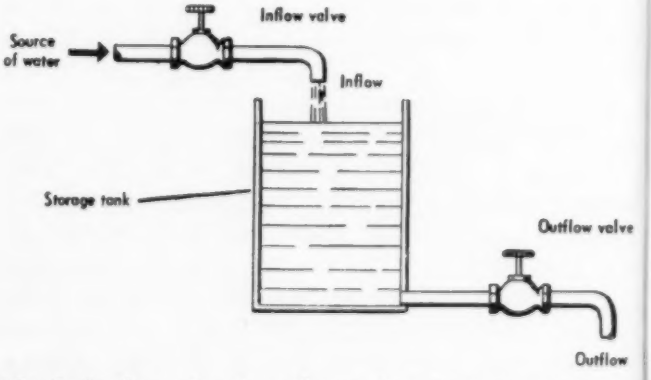
Temperature Control of Typical Reactors

As an example of temperature control, consider the pressurized water reactor as shown on page 7. The heat reservoir for this system is the circulating water that acts as coolant-moderator for the reactor and as a source of heat for the boiler. As the moderator for the reactor, the temperature of the water affects the reactivity of the reactor; and the moderator may be designed to have a negative coefficient of reactivity. Under operating conditions with no control by means of rods, this negative coefficient of reactivity causes the reactor power to assume a level that maintains constant the mean temperature of the moderator within the reactor core. As the inlet temperature of the circulating water to the reactor decreases, the mean water temperature in the reactor core tends to drop. This increases the reactivity, resulting in an increase in power so that the mean water temperature will remain approximately the same. As a result the outlet temperature from the reactor will rise.

An increase in the heat energy consumed by the load in this system causes a decrease in the temperature of the water leaving the boiler and returning to the reactor. This, as just explained, raises the power level in the reactor to meet the increased demand of the load.

Analysis and operation of this type of reactor have shown that a reactor controlled in this manner is stable for changes in the inlet temperature of the coolant. A boiler is likewise stable in its operation when supplied with approximately constant-temperature heating fluid. As a first approximation, a system composed of individually stable elements would appear to be stable. The one difficulty in the pressurized water system is that it tends to oscillate thermodynamically, and this oscillatory tendency must be counteracted by additional control devices.

Oscillation occurs because of the transport lag introduced by the circulation of the coolant-moderator



This hydraulic system is analogous to a heat-power system. The water in this analogy corresponds to heat energy so that inflow of water is equivalent to heat generation, outflow of water is equivalent to heat used or lost, and the total water stored is equivalent to the total heat content of the power system.

between the heat exchanger and the reactor core. A change in load produces a reduction in the outlet temperature of the coolant from the heat exchanger, but this change is not delivered immediately to the reactor proper. When this cooler fluid does reach the reactor core, an increase occurs in the outlet temperature of the reactor and this increase is transmitted, with a delay, back to the heat exchanger. Since the heat removal in the heat exchanger is determined by the load demand, this hotter fluid entering the heat exchanger causes the outlet temperature of the coolant-moderator to increase. This hotter fluid returns to the reactor core, producing a reduction of power and a decrease in the outlet temperature from this unit. It may be seen, therefore, that this action will continue until the oscillation damps out. This instability would be unsatisfactory in a commercial power station, and it is necessary to modify the method of control to remove it.

The coupling that produces the thermal oscillations occurs through the rise in the temperature of the water delivered from the reactor to the heat exchanger. Had this temperature remained constant, no feedback would have occurred and the system would have operated in a stable fashion. It would be more desirable for the control of this system to regulate the outlet temperature of the reactor rather than the mean temperature. Care must be exercised at this point lest the time lags of the temperature sensing-circuit introduce additional, and more serious, oscillations.

The fuel temperature may also be used to control the operation of a reactor. In the pressurized water reactor, as the power level increases the mean fuel temperature increases. If the reactor were designed to have a pronounced negative temperature coefficient associated with the fuel, then the combined effects of the fuel and the moderator coefficients may be such as to regulate, automatically, the outlet temperature of the water moderator. This action occurs because as the power level increases and the mean fuel temperature increases the mean moderator temperature must decrease to maintain a unity multiplication factor for the system.

In addition to the regulation of power in the operating range, reactor control systems must provide for starting up the system, and for safe operation under abnormal or emergency conditions.

While control rods may still be used in the design of a system to provide for these operations and for the control of the operating temperatures of the system, the amount of servo control and the accompanying electronic circuitry has been materially reduced. Future developments in reactor design may permit even these functions to be performed by other methods such as fuel enrichment for start-up and deliberate "poisoning" for emergency shutdown, and these power systems may be made to approach a simple, and almost foolproof operation.

These power systems are not intended to be research tools. They must be developed to operate as simply and with as little instrumentation and auxiliary control as possible. To accomplish this aim, systems will be designed, where possible, to use the tools provided by nature to obtain stable and reliable operation. This goal will be furthered through experience gained by operation of experimental power reactors, and through laboratory study of other possible reactor designs.

RESPONSIBILITY OF SCIENCE

"Outside the laboratories one of our chief responsibilities is to help spread information about the results of science and to impart some understanding of scientific method to our fellow citizens who have had no scientific training. The popularization of science is a difficult job, and not many of us are good at it. However, it is a collective duty that we must take seriously. We should endeavor not only to give information but also to promote those attitudes that are bound up with science. With tact and understanding we should combat prejudice, intolerance, and all forms of absolutism."

J. Rud Nielsenin in *Scientific Monthly*

NOTES from BATTELLE

* REPORTS ON NUCLEAR RESEARCH

Battelle technologists presented nine papers before the Engineers' Joint Council Nuclear Science and Engineering Congress, which was held in Cleveland, Ohio, last month.

An evaluation of molten sodium hydroxide as a possible coolant for nuclear reactors was presented by N. E. Miller and E. M. Simons. They stated that with a low maximum temperature and a small coolant thermal cycle, a reasonable lifetime might be expected for the parts of the system in contact with the caustic. They pointed out, however, that studies at Battelle on pump loops of nickel, indicate that the severe mass transfer of nickel in these systems is a serious deterrent to the use of sodium hydroxide at temperatures over 1050 F. However, a few materials that reduce the mass transfer of nickel when added to sodium hydroxide warrant further research in this area.

A method for visual study of corrosion by hot water, an important problem for designers of nuclear reactors, was described in a paper by Daniel R. Griesser and Simons. The apparatus for such studies consists of an autoclave fitted with windows for admitting light and for taking photographs. An ingenious design prevents convection currents in water covering the glass windows so as to blur the photographs. The apparatus permitted time-lapse motion pictures of specimens in black and white and color, from the moment of their contact with the high temperature water until corrosion was complete.

Another paper, "The Fabrication and Properties of Thorium", noted that thorium, a potential source of nuclear fuel, is now available in sizeable quantities and that considerable engineering data is now available about it. The authors, H. A. Saller and J. R. Keeler, reviewed several methods for producing the metal and described the properties of the pure metal.

A second paper on thorium by H. R. Ogden, R. M. Goldhoff, and R. I. Jaffee, reported that that metal can be strengthened by alloying with carbon. Thorium's tensile strength can be doubled by alloying it with 0.25 weight per cent of carbon and further strengthened by precipitation hardening and cold working. Additions of 48 other elements in dilute quantities failed to affect the strength of thorium appreciably.

The rate of diffusion of uranium through graphite has been studied by ceramists at Battelle. L. D. Loch, J. R. Gambino, and W. H. Duckworth report that in experiments with diffusion couples consisting of uranium dicarbide in contact with graphite, in the temperature range from 3000 F to 4350 F, uranium transport by volume diffusion and pore migration was observed. In volume diffusion, uranium moves through solid graphite, within crystals. Under the conditions of the study, depths of penetration by pore migration were of the order of 100 times as great as those by volume diffusion. The Institute ceramists believe that pore migration may be the most important type of uranium transport in its practical results.

The use of enamels to protect zirconium against oxidation was described in a paper by John Schultz, H. P. Tripp, B. W. King, and Duckworth. The enamels were developed from frits based on the lead silicate glass systems. Enameled zirconium was tested in air and in certain molten metals. Liquid potassium at 345 C attacked the enamels rapidly. However, the metal was protected successfully in air at 600 C for 1000 hours and in liquid lead and liquid bismuth at 345 C for 100 hours.

Battelle ceramists Collin Hyde, J. F. Quirk, and Duckworth reported that high purity beryllium oxide shapes of essentially theoretical density can be fabricated by the usual ceramic processing methods. The material is of interest to reactor designers because it is resistant to high temperatures in oxidizing atmospheres and has more efficient moderating power than most materials. Readily sinterable powders were prepared from high-purity sulfates or hydroxides of beryllium by calcination under carefully controlled conditions. Dense, strong compacts, having higher strengths than ever before reported for pure beryllium oxide ceramics, were made at moderate sintering temperatures.

Phase relationships in the hydrogen-uranium system were reviewed by M. W. Mallett, M. J. Trzeciak, and C. B. Griffith. They reported new data on the solubilities of hydrogen in uranium at one atmosphere pressure over a temperature range from 450 to 950 C and on the diffusion coefficients for hydrogen in uranium at temperatures from 390 to 724 C. The authors state that the reaction mechanism is complex and warrants more thorough investigation. In a second

paper, Mallett and Trzeciak presented data from which two uranium-hydrogen phase diagrams were constructed—hydrogen at atmospheric pressure and hydrogen at the dissociation pressure of uranium hydride.

ENZYMES AND TOBACCO AGING

Unaged tobaccos appear to irritate the membrane tissues of smokers and also to lack in taste and aroma. Therefore, it is customary to age tobaccos for at least 18 months. Yet little is known about what takes place during the aging, or curing, process. To learn more about tobacco curing, the American Tobacco Company recently sponsored at Battelle an investigation of the mechanisms involved in this process.

One or more of the following mechanisms probably play a part in the curing of both Bright (flue-cured) and Burley (air-cured) tobaccos: natural-occurring enzymes, bacterially released enzymes, or chemical effects.

Robert E. Barrett reports that the Battelle study of enzyme activity showed a marked difference between the flue- and air-cured tobaccos. In the latter, enzyme activity was detected for an oxidase, catalase, protease, invertase, cellulase, typrosinase, and probably decarboxylase and peroxidase. In the Bright tobacco, however, the only appreciable enzyme activity found resulted from decarboxylases. Others were either undetected or exhibited little activity. This suggests that the aging of Bright tobacco involves mostly chemical effects while the aging of Burley probably involves both chemical effects and enzymes. Further investigation of minor changes (either chemical or enzymic in orgin) is the natural next step in gaining understanding of the aging process.

TRANSISTOR SIMULATOR

Transistor simulators are of great value in the study of transistor design and transistor circuits. Such a simulator was recently described by J. Lüscher and P. Choquard at Battelle's Geneva laboratory, before the International Symposium on Analog Computers at Brussels.

The Battelle technologists reported the development of a general analog circuit utilizing vacuum tubes, that can simulate the most important working mechanisms of the junction transistor. With a simplified model of this analog they were able to simulate the small signal behavior of various junction transistors. Lüscher and Choquard report that by inserting the simulator into a circuit, it is possible to determine the parameters and design structure required for the transistor to be used in the circuit under consideration. Thus the simulator makes possible the determination of the properties required in a transistor before the latter is constructed.

U. S. EXPORTS TO CANADA

A research survey to determine the source and value of United States exports to Canada is being conducted by Battelle for the Canadian Institute of International Affairs.

The survey's results are expected to yield valuable information that has never been gathered before and which, it is thought, will assist businessmen in both the United States and Canada.

For instance, manufacturers will have a reference which will tell them the types and kinds of imports Canadians buy from the United States.

Economists may find the survey results of value since they will then be able to determine the value of Canadian purchases of U. S. manufactured goods to the community in which the manufacturer is located. Canadians will know the origin of their major imports and the communities on which they are most dependent for imports from the U. S.

Chambers of commerce throughout the United States are cooperating in the study.

RESEARCH MANPOWER NEEDS

Nearly one-half million new research scientists will be required to meet the country's minimum needs by 1975, John S. Crout, vice president of Battelle, stated recently in an address before the Cleveland Chapter of the National Society for Business Budgeting.

He pointed out that there are approximately 500 thousand people presently employed in all types of scientific research in the United States. These people conducted over $4 billion worth of research in 1955. Both government and industry agree that national research activity in 1975 should be in the order of magnitude of $16 billion annually. Allowing for such factors as increased efficiency in research operations and higher per project costs as science becomes more complex, it has been estimated that 800 thousand professional research workers will be required to handle such an annual volume of research.

Thus, Mr. Crout point out, there must be a net addition of 300 thousand men to the profession in the next 20 years. Inasmuch as one-third of the present force will probably retire, transfer to other work, or die in that period, at least 467 thousand new entrants into the field would be required to achieve a net addition of that amount.

At the present rate of training of engineers and scientists, it will be impossible for the Nation to meet its predicted future needs for research manpower, Mr. Crout said. The training of 467 thousand research scientists in 20 years would mean an average of more than 23 thousand per year, he stated. But our colleges and universities are presently turning out only about 12 thousand people per year who are interested in, or qualified for, research. Thus, the present rate of increment to the Nation's professional research force is hardly more than 50 per cent of that needed to meet conservative forecasts of future demand.

This shortage will be solved, Mr. Crout said, by the attraction of more young men and women to careers in science and engineering. Thus, the Nation's potential for technical and economic progress will be realized.

* NEW LIGHT ON CHROMIUM

Oxygen, sulfur, and nitrogen, present as impurities in commercial chromium, impart hot shortness to chromium-rich chromium-iron and chromium-nickel alloys. D. J. Maykuth and R. I. Jaffee, metallurgists at Battelle reached this conclusion after fabricating such binary alloys both with 99.99 per cent pure iodide chromium, and with commercial chromium. The results of their study were presented in a paper at the Chromium Symposium of the American Society for Metals in Philadelphia.

Binary alloys of chromium with vanadium, molybdenum, tungsten, columbium, or tantalum could not be hot rolled to sound sheets, even when made with the very pure iodide chromium. The workable alloy systems, found in this research for the U. S. Air Force Aeronautical Research Laboratory at Wright-Patterson Air Force Base, were chromium-iron, chromium-nickel, and chromium-cobalt combinations. In these alloys, strengths increase and ductilities decrease in proportion to their chromium content, according to bend and tensile tests. Best combinations of strength and ductility were exhibited by chromium-rich chromium-nickel alloys.

A chromium-iron-base alloy exhibiting good high-temperature strength and resistance to thermal shock was described in a paper by D. P. Moon, H. A. Blank, and A. M. Hall, also given at the Chromium Symposium. The alloy, produced as a result of research at Battelle for the Materials Laboratory of the Wright Air Development Center, can be created from commercially available melting stock with a process adaptable to commercial use. Ingots weighing up to 12 pounds have been forged. At room temperature this alloy is malleable, but it does not exhibit measurable ductility. With these properties, alloys of this type are useful in such high-temperature applications as jet engines.

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In an investigation of production of dense, high-purity magnesia ceramics, Battelle Institute ceramists found that density is affected markedly by the physical form of the powder from which they are made. By use of proper heat treatment in calcining the magnesia powder, ceramic bodies with zero apparent porosities were obtained at sintering temperatures as low as 1650 C. Moreover, A. G. Allison, E. C. Sesler, Jr., N. L. Haldy, and W. H. Duckworth report that for each species of magnesia powder there appears to be an optimum calcining temperature to obtain powders that densify most readily. Although the study was limited to magnesia, they believe that the same techniques would be useful for simplifying preparation of dense ceramics of other high-purity oxides.

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Recently, in the course of a research program, John E. Gates and David F. Edwards of Battelle found it necessary to prepare a point source of promethium-147. Taking a tip from published data on the electroplating of yttrium, neodymium, and lanthanum, they investigated this method for preparing the needed point source. They report that they were able to electroplate the metal onto a platinum wire in a solution of 98 per cent ethylene diamine. The deposited material was black in color, adherent, and had little metallic luster. It was not determined whether the deposit was the metal or the oxide.

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Correction: Specifications for alumina cell feed include a maximum of 0.25 percent potassium instead of 25 percent as stated on page 159 of the *Battelle Technical Review* for December, 1955.